GEOMORPHOLOGY AND INCONNU SPAWNING SITE SELECTION: AN APPROACH USING GIS AND REMOTE SENSING

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A

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ABSTRACT

This study examined the spatial components of inconnu *Stenodus leucichthys* spawning habitat use in the Selawik River, Alaska. Little is known about inconnu critical habitat needs; however, current studies of inconnu spawning behavior suggest a high level of habitat selectivity. This level of selectivity implies that there are specific habitat characteristics that these fish require for spawning. The purpose of this study was to build a heuristic habitat model that can be used to better understand inconnu spawning site selection in remote Alaskan watersheds. Using readily available, low- or no-cost remote sensing data layers, geographical information systems (GIS) were used in conjunction with multivariate statistics in an attempt to clarify relationships between geomorphologic features and spawning site selection. Spatial resolution of the remotely sensed data available in this study did not provide sufficient spatial detail to generate statistical correlations between spawning habitat selection and landscape characterizations. However, spawning occurred in areas of transition from high to low gradients, and in reaches typified as having very low slopes with very high sinuosity. Additionally, exploratory use of Radarsat fine beam 1 data favored its future application in fisheries investigations. This study is an initial step toward more research into inconnu spawning habitat.

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INTRODUCTION

Biologists regularly exam spatial components to address fisheries questions, be it to fill data gaps or for management needs (Rahel 2004). These spatial components may be comprised of fish species composition and distribution; identification of critical habitats and migratory corridors; or habitat use in relation to location and juxtaposition of landscape variables. Addressing these spatially explicit questions in Alaska poses unique and difficult challenges. The distance, area, and remote nature of study sites combined with the expense of in-stream studies and limited resources have created a dearth of information regarding some of Alaska's freshwater species (Morrow 1980). The use of geographic information systems (GIS) and remote sensing is one way to affordably analyze and display spatial data to determine the attributes of fish habitat; to determine what spatial patterns exist; and to direct modeling efforts (Isaak and Hubert 1997, Rahel 2004). For this study, these techniques were directed at better understanding spawning habitat use by inconnu *Stenodus leucichthys* in the Selawik River drainage basin.

Inconnu, commonly known as sheefish in Alaska, are a large salmonid in the whitefish subfamily (Table 1; Mecklenburg et al. 2002). In 1980, Congress recognized the importance of inconnu in the Alaska National Interest Lands Conservation Act (ANILCA). Through ANILCA, Congress mandated that inconnu be maintained in their natural diversity and that opportunities for their subsistence use remain consistent on federal lands within Alaska (USFWS 1993). Inconnu are currently used in subsistence,

Table 1. Taxonomic classification of inconnu (adapted from Mecklenburg et al. 2002).

Scientific Nomenclature	Inconnu
Class	Actinopterygii
Order	Salmoniformes
Family	Salmonidae
Subfamily	Coregoninae
Genus	*Stenodus*
Species	*leucichthys*
Subspecies	*nelma*

commercial, and sport fisheries (Georgette and Loon 1990; Brown 2007).

Distribution

The inconnu subspecies *S. l. nelma* is distributed within North American arctic drainages from the Anderson River in Northwest Territories, Canada to the Kuskokwim River in Alaska (Scott and Crossman 1973). *S. l. nelma* also occurs across areas of Siberia. An isolated subspecies of inconnu *S. l. leucichthys* occurs in the northern Caspian Sea and its tributaries (Morrow 1980).

Alaskan drainages with inconnu populations include the Kobuk, Selawik, Yukon, and Kuskokwim systems (Figure 1; Morrow 1980; Mecklenburg et al. 2002). Within the Yukon River drainage, Alt (1970, 1985) reported inconnu spawning in the Koyukuk and Alatna Rivers and in the Sulukna River. Brown (2000) identified inconnu spawning grounds within the Yukon River main stem above the Porcupine River. The Kobuk-Selawik population winters in Selawik Lake and the brackish water of Hotham Inlet, with the Selawik River fish spawning near the Ingruksukruk Creek mouth (Underwood et al. 1998; Hander et al. 2008) and in the Tagagawik River (R. J. Brown, USFWS, personal communication) and the Kobuk River fish spawning upstream of Kobuk Village (Alt 1969; Taube and Wuttig 1998).

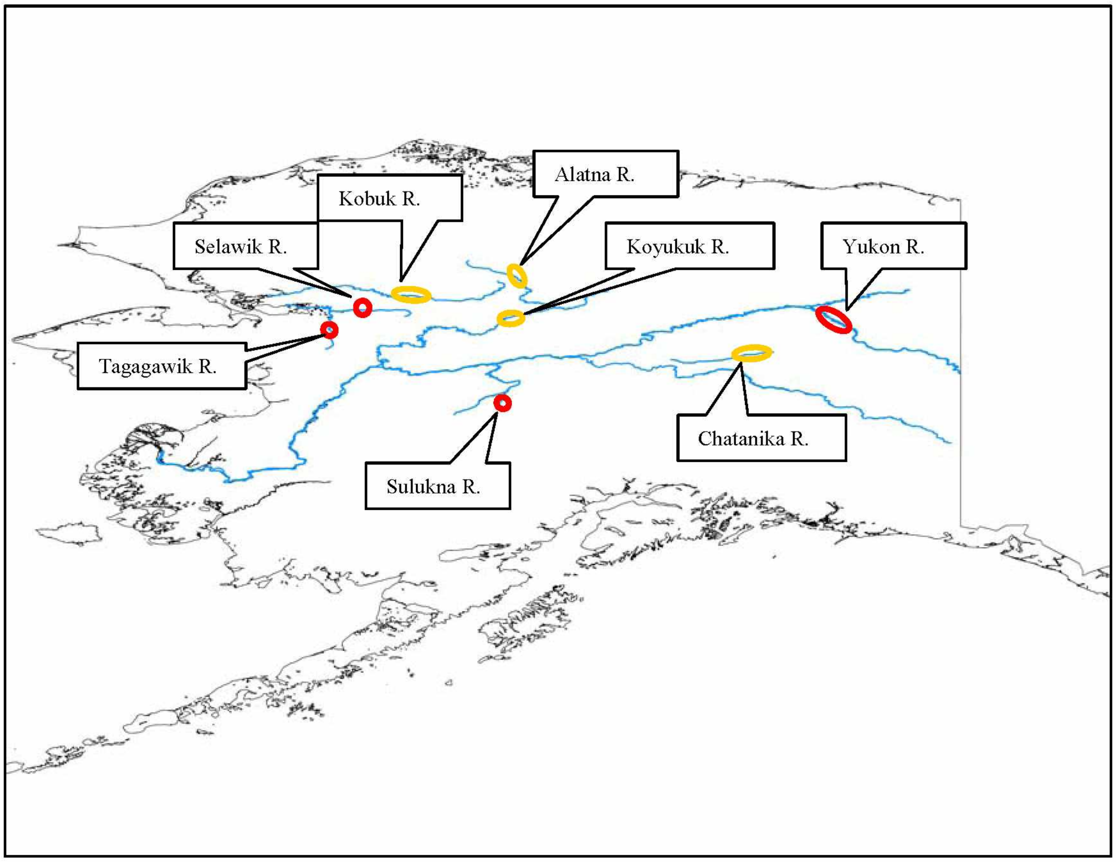

Figure 1. Known inconnu spawning areas in Alaskan rivers. Spawning areas depicted in red have been defined through telemetry work. Spawning areas depicted in yellow are reported in the literature, and have not yet been spatially defined by telemetry.

Life History

Inconnu populations in different river systems are subject to different sets of environmental variables that affect growth rates, age at maturity, maximum size, and lifespan. In general though, males reach sexual maturity at an earlier age and smaller size than do the females (Alt 1985). Howland (1997) used otolith age analysis in the Mackenzie River system, and reported age 9 females and age 7 males as the youngest fish found in spawning condition. Using similar aging techniques, Brown (2000) reported age 7 as the minimum age of females and males in spawning condition from a Yukon River migration. Once sexually mature, inconnu may spawn many times at intervals of one or more years for the remainder of their lives (Taube and Wutiig 1998; Underwood 2000; Hander et al. 2008), which may extend 30 years (Howland 1997; Brown 2000).

Upstream migrations from the wintering areas begin during the spring ice breakup period. Adult and juvenile inconnu move to summer feeding habitats, from which pre-spawning adults migrate to spawning areas after pausing to feed (Alt 1977). In coastal areas, inconnu are anadromous, with upstream migrations that may reach distances of 1,700 to 1,800 km (Stephenson et al. 2005; Brown 2007). Inconnu do not feed in the later phase of the spawning migration (Alt 1969; Howland 1997; Brown 2000), instead they utilize body fat reserves. In freshwater populations, adults undertake similar migrations of shorter distances. Spawning occurs in late September to early October. Unlike salmon, inconnu do not build redds. Alt (1969) observed that female inconnu released their eggs near the water surface while males swam below fertilizing them. The fertilized eggs drift downstream and to the bottom, lodging in the gravel substrate. Following spawning activities, adults undertake a rapid downstream migration to their wintering grounds where feeding resumes. Fertilized eggs take several months to hatch (Morrow 1980). The emergent fry travel downstream, carried by the spring floods (Reist and Bond 1988). Fry feed on plankton initially, then quickly switch to insects and small fish. By their second year, inconnu are exclusively piscivorous (Alt 1973).

Little is known about inconnu critical habitat needs for spawning. Current studies of inconnu spawning behavior suggest a high level of habitat selectivity, which implies that there are specific habitat characteristics that these fish require for spawning. Since the 1990s, several telemetry studies have identified spawning reaches for inconnu in North American basins, including the Selawik River (Underwood et al. 1998; Hander et al. 2008), Yukon River (Brown 2000), Mackenzie River (Howland et al. 2000), and Nowitna River (R. J. Brown, USFWS, personal communication). In each of these drainages, site fidelity appears to be strong. Inconnu, as well as other coregonids, seem to spawn in an especially limited portion of a basin. For example, within the entire Selawik drainage, inconnu appear to utilize approximately 18 river km of the drainage for spawning (Underwood et al. 1998; Hander et al. 2008; R. J. Brown, USFWS, personal communication).

As of yet, there are few reports on specific measures of spawning habitat parameters. Most of the data available are descriptive. Spawning habitat characteristics include a swift current in areas with substrate composed of differentially sized gravel (Alt 1971, 1987). Generally, the water depth is 1.2 m to 2.7 m with temperatures of 4.6°C and colder (Morrow 1980; Howland 1997). The lack of habitat data is a reflection of both the high costs (logistical, financial, and time) associated with in-stream habitat measures in remote Alaskan drainages and the limited resources available to collect this data.

One way to circumvent the high costs associated with in-stream habitat surveys is to examine a basin at a larger scale. Basin geomorphic processes occur at various scales, and each one plays some part in determining the structure of the river (Thompson et al. 2001). Drainage basin morphology influences finer-scale habitat variables, which in turn, influence biologic communities (Richards et al. 1996). For example, climate and underlying geology influence the slope of a reach, sediment load, and water discharge. The slope of a reach, along with its water and sediment inputs from the contributing drainage, will in turn determine potential channel features, such as pool/riffle morphology (Frissell et al. 1986). Channel features at the reach scale, e.g. gravel bars and islands, affect specific hydraulic features of potential spawning habitat (Figure 2; Geist and Dauble 1998). By understanding the multiscalar relationships between physical characteristics and their relevance to aquatic communities, it is reasonable to develop a cost effective, large-scale heuristic model for inconnu spawning habitat selection. Additionally, this level of modeling should narrow the set of variables needed for lower level investigations.

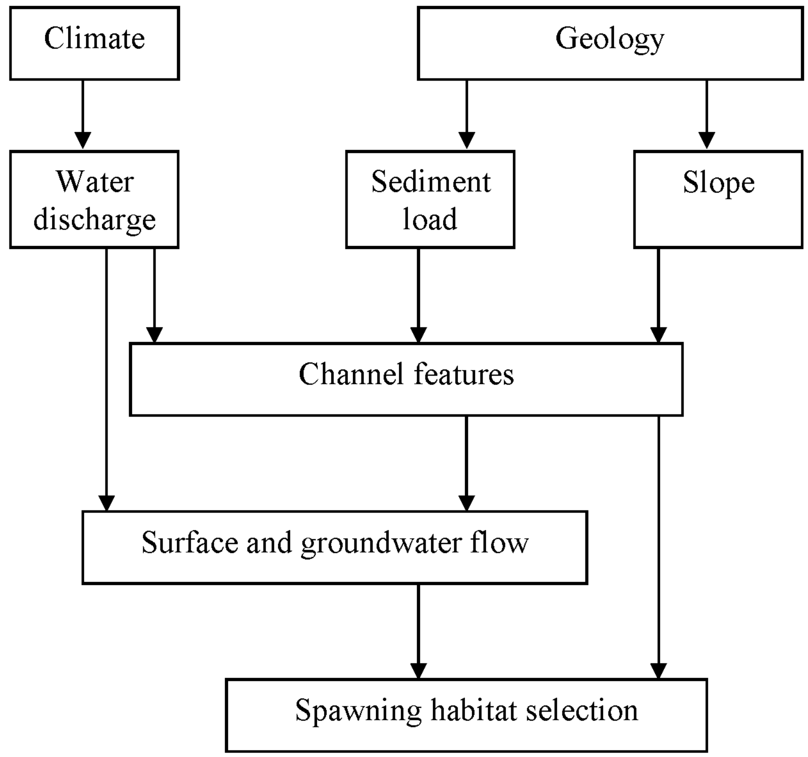

Figure 2. The multiscalar relationships that influence spawning habitat selection. Large-scale drainage basin variables affect finer-scale variables, which in turn influence biologic communities.

My specific research objectives were to:

1. Quantify and describe landscape-level characteristics of the basin within the Selawik River drainage to build a heuristic model for inconnu spawning habitat, and
2. Make recommendations based on the use and application of GIS and remotely sensed data and maps for similar work in remote basins.

STUDY AREA

The Selawik River, a designated National Wild and Scenic River, is located within the Selawik National Wildlife Refuge in northwestern Alaska (Figure 3). The Selawik Refuge straddles the Arctic Circle and is composed of estuaries, lakes, river deltas, and tundra slopes. The Selawik National Wildlife Refuge is partially bordered by the Kobuk Valley National Park to the north and the Koyukuk National Wildlife Refuge to the south (USFWS 1993). The Selawik River originates within the wide tundra valley of the Percell Mountains and drains into Hotham Inlet. All rivers in the Selawik drainage are non-glacial in origin. The Selawik River has three important tributaries: the spring-fed Tagagawik River, which drains out of the Selawik Hills and Purcell Mountains; the Kugarak River, which drains out of the Waring Mountains and Shekluksuk Range; and the Fish River, which drains from the Waring Mountains. Additionally, the headwaters of the Selawik River include several hot springs (USFWS 1993). The Selawik River has an approximate drainage area of 11,700 km^2 (DeCicco 2004), an area nearly the size of Connecticut.

The region has a generally marine climate through the summer and long, cold winters. Temperature extremes may range from 34°C to minus 51°C. Most of the precipitation occurs during the summer months, with annual precipitation ranging from 38 to 51 cm in the lowlands and up to 76 cm in some areas of higher elevation (USFWS 1993). The Selawik River delta is underlain by continuous permafrost. Area soils are formed from

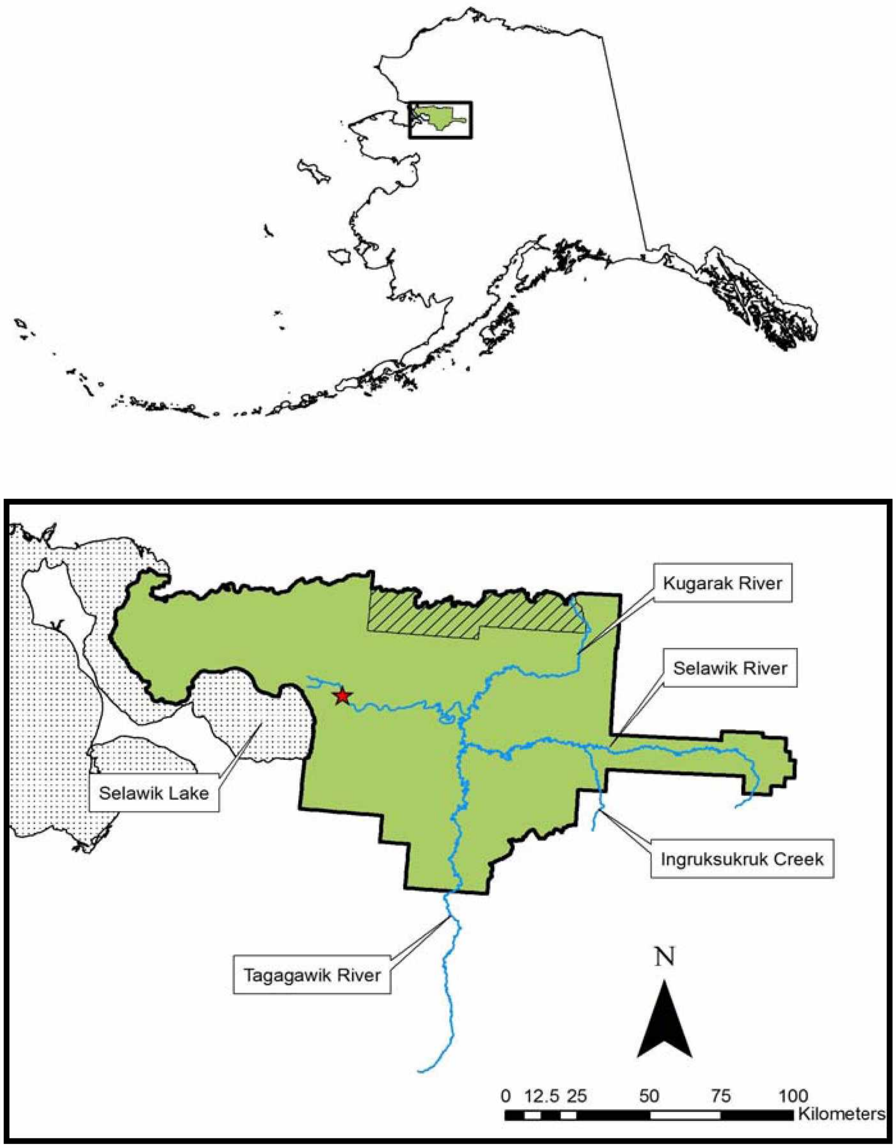

Figure 3. Location of the study area in northwestern Alaska (top). Most of the Selawik River drainage lies within the Selawik National Wildlife Refuge (NWR; green). The upper portion of the Selawik NWR hosts a designated wilderness area (inset, crosshatching). The village of Selawik is located near the mouth of the Selawik River (inset, red star).

stratified alluvial deposits, both silty and sandy, as well as volcanic ash and loess (McNab and Avers 1994). There are three vegetation types present, including tundra, forest communities, and grasslands (USFWS 2005). Human development in the area is sparse. The only community in the area is Selawik Village, with approximately 800 residents (U.S. Census Bureau 2008). The village is situated near the mouth of the Selawik River (66.60314^{o}N, 160.01042^{o}W). Additionally, there are scattered native allotments and traditional hunting and fishing campsites within the basin.

METHODS

Habitat Characteristics

To develop the heuristic habitat model in the most financially conservative manner, only readily available low- or no-cost data layers were acquired. In total, five sources of data were used to derive habitat characteristics for each of the sample reaches using ArcMap software (ESRI 2006). A sixth data source was employed for only the Selawik spawning area (Table 2).

Two sets of reaches were selected for sampling. The first set consisted of the known spawning reaches within the Selawik basin, which were identified from radio telemetry studies. Underwood et al. (1998) and Hander et al. (2008) both report spawning locations on the Selawik River in the area of the Ingruksukruk Creek mouth. This area was artificially separated into two sample reaches, one on each side of the Ingruksukruk Creek mouth. In addition to the Selawik River spawning area, a second spawning area was identified on the Tagagawik River in fall 2007 (R. J. Brown, USFWS, personal communication). These studies provided the three spawning reaches (Figure 4) for use in this modeling effort. The second set of reaches selected for sampling consisted of 15 non-spawning reaches randomly selected from within the basin (Figure 4). A digital line graph (DLG) of streams at 1:2,000,000 was obtained for the basin (USGS 2003). Each segment of the stream DLG is associated with a unique identifier, and these segment identifiers were used in conjunction with a random number table to select the streams

Table 2. Original primary data sets and their corresponding derived secondary data, scale, and sources.

Data Layer	Derived Data	Scale	Source
DLG	Stream reach identification	1:2,000,000	USGS
Landsat 7 TM	Sample reaches	30 m	
	Sinuosity		USGS
DEM	Elevation		
	% Slope	30 m	
	Artificial stream networks		USGS
Surficial geology	Surficial geology	1:1,584,000	NPS/USGS
Permafrost	Permafrost	1:2,500,000	USGS
SAR FN1	River ice condition	~ 9 m	UAF ASF

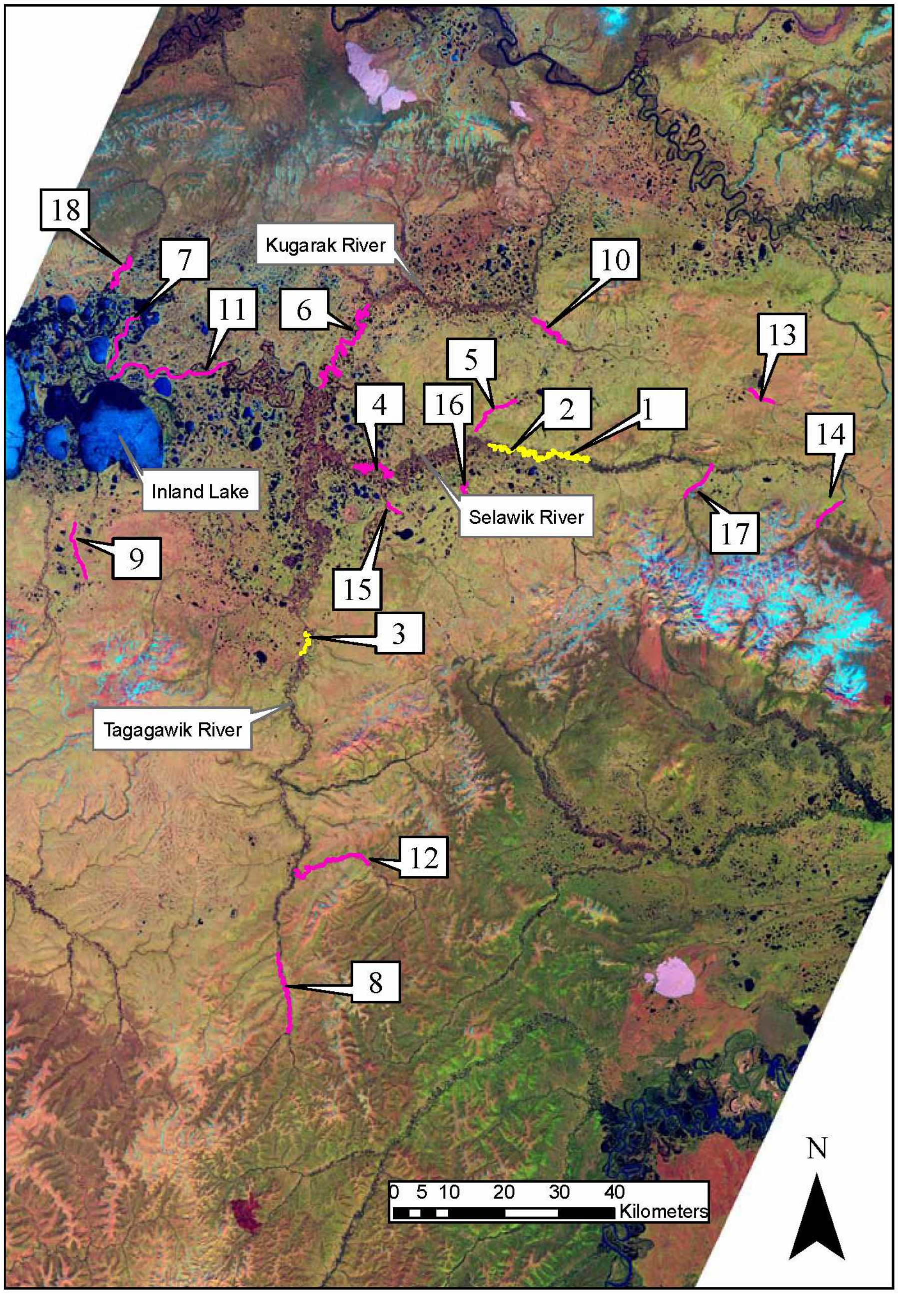

Figure 4. Sampling reaches within the Selawik basin. Pink represents the 15 randomly selected non-spawning reaches and yellow represents the three known spawning reaches. Each reach is assigned an identification number (Table 3).

Table 3. Sample reaches and their corresponding classification results.

ID	Name	Spawning Detected	Sinuosity Value	Sinuosity Type	Slope Value (%)	Slope Type	Surficial Geology Deposit Name	Permafrost Code
1	Selawik River	Yes	2.27	Very High	0.10	Very low	Fluvial	22
2	Selawik River	Yes	2.10	Very High	0.10	Very low	Fluvial	22
3	Tagagawik River	Yes	1.70	Very High	0.23	Very low	Undifferentiated alluvium & colluvium	22
4	Selawik River	No	3.10	Very High	0.00	Very low	Fluvial	22
5	Kawichiark River	No	1.31	Moderate	0.06	Very low	Mountain alluvium & colluvium	22
6	Kugarak River	No	2.36	Very High	0.00	Very low	Fluvial	22
7	Unnamed	No	1.17	Moderate	0.00	Very low	Coastal	22
8	Tagagawik River	No	1.49	High	0.35	Very low	Undifferentiated alluvium & colluvium	22
9	Hunt Creek	No	1.17	Low	0.34	Very low	Coastal	22
10	Rabbit River	No	2.27	Very High	0.10	Very low	Fluvial	22
11	Selawik River	No	1.21	Moderate	0.03	Very low	Coastal	22
12	Derby Creek	No	1.90	Very High	0.25	Very low	Undifferentiated alluvium & colluvium	22
13	Kiliovilik Creek	No	1.38	Moderate	0.63	Low	Undifferentiated alluvium & colluvium	12
14	Shiniliaok Creek	No	1.29	Moderate	0.72	Low	Glacial moraines & drift	22
15	Ekiek Creek	No	1.16	Very High	0.38	Very low	Fluvial	22
16	Kerulu Creek	No	2.04	Very High	0.35	Very low	Undifferentiated alluvium & colluvium	22
17	Shinilikrok Creek	No	1.18	Low	0.59	Low	Glacial moraines & drift	22
18	Fish River	No	2.41	Very High	0.01	Very low	Coastal	22

to be used for comparison against the known spawning areas. These random reaches were defined using the USGS (2000) confluence-to-confluence rule. DLG files are digital vector files representing cartographic information. One problematic issue was the representative accuracy of the DLG in comparison to the actual river or stream (Priestnall and Aplin 2006). To better represent the sample stream reaches, each sample reach was hand digitized from remotely sensed Landsat images.

I acquired two Landsat 7 Thematic Mapper (TM) scenes for 17 June 2001 based on their minimal cloud cover (0%). The image center for the northern portion of the drainage was located at approximately 66.9°N, -157.7°W. The image center for the southern portion of the drainage was located at approximately 65.6°N, -159.0°W. These scenes were projected into a NAD 83 AK Albers spatial reference. For bands 1 though 5 of each scene, I created a mask of no data around the scene itself to eliminate the scene borders. Once this task was completed, a composite of bands 1 through 5 was created to form a single red-green-blue (RGB) image. Finally, the northern and southern RGB images were merged into a single mosaic of the drainage. With the randomly selected stream segments from the DLG as a guide, I hand digitized more accurate and current sample reaches from the Landsat mosaic. Using the Landsat-derived sample reaches, sinuosity values were estimated as the ratio of stream length to basin length. These values were then interpreted as low, moderate, high, or very high (Table 4; Arend 1999).

Table 4. Stream type classification for sinuosity and slope. These are based on interpretive classes from measured values (Source: Arend 1999).

Criterion	Measured Value	Interpretation
Sinuosity	<1.2	Low
	>1.2	Moderate
	>1.4	High
	>1.5	Very high
Slope	>10%	Very high
	4-10%	High
	<4%	Moderate
	<2%	Low
	<0.5%	Very low

My third data source was a seamless two arc second Digital Elevation Model (DEM) obtained from the U.S. Geological Survey (USGS) National Elevation Dataset (NED). In Alaska, the NED 2 Arc Second DEM is a raster product in seamless form with a consistent datum, elevation unit, and projection. The NED is a living dataset, with regular updates to incorporate best-available new coverage (USGS 2008). Four ~60-m DEMs were needed to cover the Selawik drainage. In GIS, these were projected into the same spatial reference as the Landsat mosaic. Each of the separate DEMs was stitched together into a single raster mosaic and then filled to generate a depressionless DEM. From this DEM, the pattern of elevation change for the sample reaches based on lowest and highest elevations was estimated as percent slope. The slope values were in turn interpreted as being very low, low, moderate, high, or very high (Table 4; Arend 1999). Additionally, I created an artificial stream network within the Selawik basin boundaries from the DEM mosaic. With the filled DEM mosaic, I defined flow direction for each cell and created a flow accumulation layer. Using the raster calculator, I delineated the artificial streams using an accumulation of water from 150 cells to define channel cells. Non-channel cells were then reclassified to NoData. The new channels were then assigned a unique code, resulting in a raster-based artificial stream network that can be used to determine stream linkages and stream orders (Fisher and Rahel 2004). Finally, I converted the raster artificial stream network into a polyline shapefile.

Two other primary sources from which data were derived include a surficial geology coverage and a permafrost coverage. The surficial geology map designates 25 different deposit types that are divided into 10 classifications, including ice for glaciers and water for lakes, and was at a 1:1,584,000 scale (NPS and USGS 1999). The geologic classifications, or deposit names, were used to describe the surficial geology of the sample reaches (Table 5). The permafrost map was at a scale of 1:2,500,000. The permafrost coverage represents the correlation of physiographic province to presence of permafrost and assigns nine possible unique classifications (Table 6; USGS 1996).

Statistical Analysis

Analysis of spawning habitat selection in relation to landscape characteristics was based on presence/absence of spawning as determined by radio telemetry work (Underwood et al. 1998; Hander et al. 2008; R. J. Brown, USFWS, personal communication). Discriminate functions analysis is a multivariate statistical method that detects patterns of variation in a response variable best explained by environmental data (Johnson and Gage 1997), a formulation called predictive discriminate analysis (Williams 1983). Here it was used to determine which habitat variables (e.g. slope, sinuosity, surficial geology, permafrost) discriminated between the spawning and non-spawning study reaches. Discriminate analysis (PROC DISCRIM) was completed using SAS 9.2. Specifically, non-parametric (NPAR) analysis was used with CROSSVALIDATE and CROSSLIST options (SAS 2007). Kernel methods are free of parametric assumptions and have acceptable, well-understood statistical properties (Worton 1989). Goutte (1997) demonstrated the suitability of cross-validation as a bias-reduction technique for small data sets. When cross-validation is used in nonparametric analysis, the covariance

Table 5. Surficial geology classifications (deposit name) and their corresponding deposit types used for reach classification (NPS and USGS 1999).

Deposit Name	Deposit Type
Coastal	Beach
	Coastal delta
	Old marine & alluvium
Eolian	Sand dune
	Upland loess
	Valley loess & alluvium
Fluvial	Alluvial fan
	Alluvial terrace
	Floodplain
Glacial moraines & drift	Highly modified moraine
	Moderately modified moraine
	Lightly modified moraine
Glacio-fluvial	Current glacial outwash
	Old glacial outwash
Glacio-lacustrine	Proglacial lake
	Proglacial lake over moraine
Ice	Glacier
Mountain alluvium and colluvium	Bedrock & course rubble
	Coarse & fine rubble
	Volcanic
Undifferentiated mosaic	Undifferentiated alluvium & colluvium
Water	Lake

Table 6. Permafrost classifications and their corresponding codes used for reach classification (USGS 1996).

Permafrost classifications	Permafrost codes
Mountainous area underlain by continuous permafrost	11
Mountainous area underlain by discontinuous permafrost	12
Mountainous area underlain by isolated masses of permafrost	13
Lowland and upland area underlain by thick permafrost	21
Lowland and upland area underlain by moderately thick to thin permafrost	22
Lowland and upland area underlain by discontinuous permafrost	23
Lowland and upland area underlain by numerous isolated masses of permafrost	24
Lowland and upland area underlain by isolated masses of permafrost	25
Lowland and upland area generally free of permafrost	26

matrices used to compute distances are based on all observations in the data set, including the observation being classified; however, the observation being classified is excluded from the *k* nearest neighbors of that observation (SAS 2007).

Accuracy for the model was judged on two elements. First, a high eigenvalue reflects the ratio of importance of the dimensions which classify cases of the dependent variable. Second, I considered the percentage of input reaches correctly classified by the discriminate function as being either spawning or non-spawning reaches (Rice et al. 1983).

SAR FN1

One source of remote data acquired was localized on the Selawik River spawning location only. An exploratory use of fine beam synthetic aperture radar (SAR FN1) was attempted to remotely examine river ice conditions of a known spawning site. RADARSAT-1 data were acquired for a 50 km swath centered on 66.48°N, -158.10°W at a ground resolution of approximately 9 m. Image acquisitions occurred one to three times per month from October 2004 to November 2005. From these, one image from the latter half of each month was selected and analyzed for October 2004 through May 2005 (Table 7). Images received from the Alaska Satellite Facility (ASF) at the University of Alaska Fairbanks were processed using the ASF supported software MapReady (ASF 2008). In MapReady, CEOS Level 1 files were terrain corrected using the DEM to minimize the distortions introduced by the side-looking geometry of the radar sensor and

Table 7. SAR FN1 acquisition information for images used to study river ice conditions. Information includes the date of acquisition, their orbit identification, and beam type.

Date	Orbit	Beam
10/21/04	46793	FN1
11/23/04	47257	FN1
12/17/04	47600	FN1
01/25/05	48165	FN1
02/27/05	48629	FN1
03/23/05	48972	FN1
04/16/05	49315	FN1
05/01/05	49537	FN1
05/25/05	49880	FN1

were spatially referenced into UTM Zone 4. Processed images were exported as geotiffs in byte format using a statistical 2 Sigma sample mapping method. From these processed scenes, river ice delineation was attempted throughout the winter season of freeze-up to thaw using the radar backscatter coefficients (Jeffries et al. 2005). Additionally, a visual interpretation was completed, categorizing the river imagery into four interpretive classes (Table 8; Puestow et al. 2004). Photographs taken on a 26 April 2005 aerial survey of the area were used in conjunction with a SAR FN1 image acquired on 1 May 2005 to compare the ice categorization to actual river ice conditions.

Table 8. SAR FN1 river ice interpretive classes (Puestow et al. 2004).

Interpretive Ice Classes	Description
Dark Ice/Open Water	Smooth ice cover or open water
Medium-Dark Ice	Ice cover with some roughness
Medium-Bright Ice	Rough ice/consolidated ice cover
Bright Ice	Heavily consolidated ice cover

RESULTS

Habitat Variables

All of the 18 reaches were characterized using derived data and maps (Table 3). The three spawning reaches were typed as having very low slopes with very high sinuosity and occur in lowland areas containing moderately thick to thin permafrost (Figure 5). The only difference between the Tagagawik spawning reach and the Selawik spawning reaches at this scale of investigation was the surficial geology type at each location. The Selawik reaches were within an area of fluvial matter while the Tagagawik reach is considered to contain undifferentiated alluvium and colluvium (Figure 6). For the 15 non-spawning reaches, most of these were also best described as having low to very low slope types and fall within lowland and upland areas containing moderately thick to thin permafrost. For the sinuosity classification of the non-spawning areas, most (12 reaches) were considered to have very high or moderate sinuosity while only two non-spawning reaches were described as having low sinuosity. At the landscape scale, surficial geology varied the most between all 18 of the reaches, but among spawning and non-spawning reaches, there was still overlap in characterization attempts. Eight of the non-spawning reaches shared fluvial or undifferentiated alluvium/colluvium surficial geology types with the spawning reaches. Additional secondary data were sought from the DEM layer in the form of a derived artificial stream network. The Selawik River is within a low relief basin, especially its extensive floodplain. According to the USGS (2008), the NED 2 Arc Second DEM has a vertical accuracy of +/- 7 to 15 meters. The combination of low-

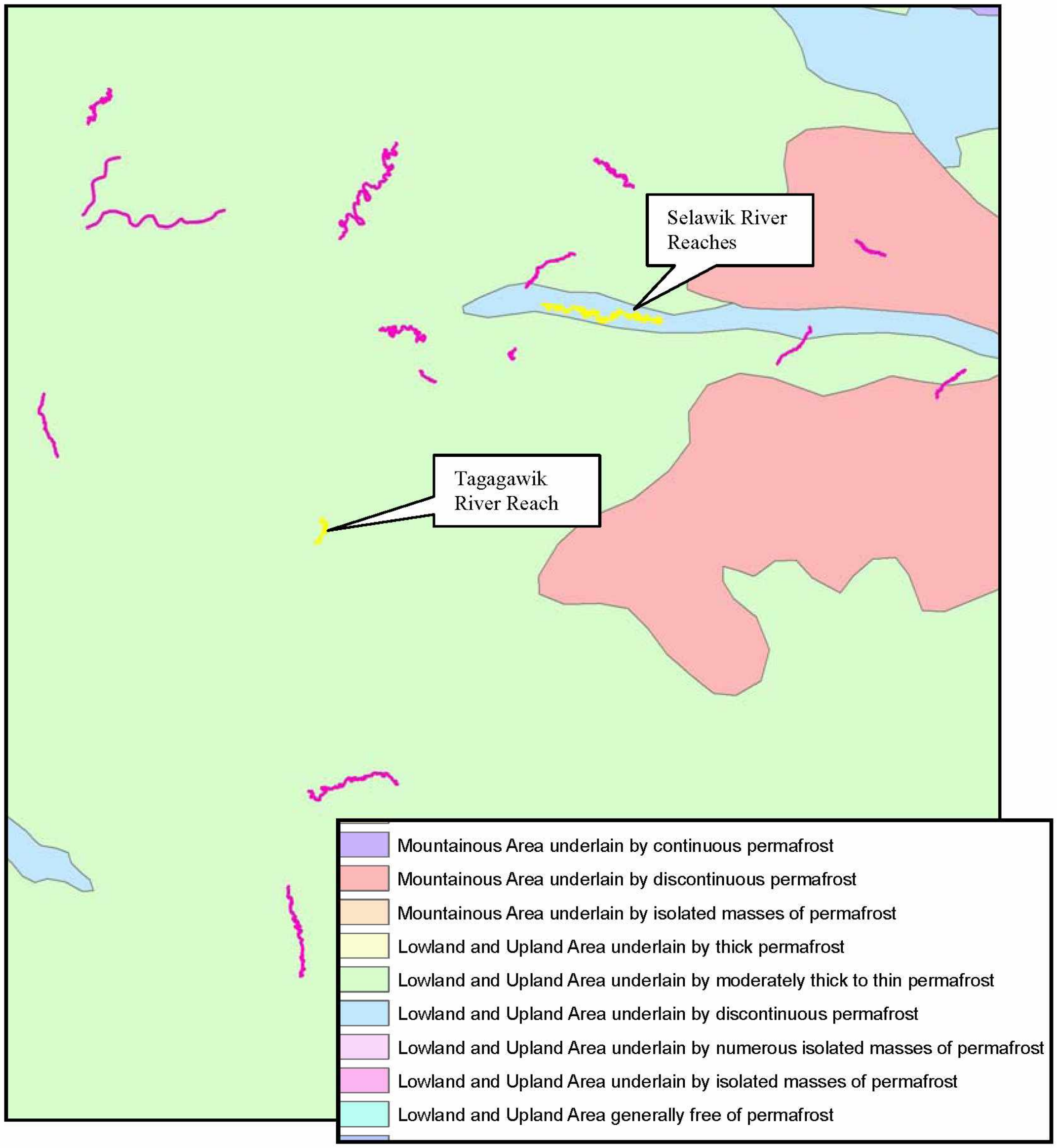

Figure 5. The sample reaches situated over the permafrost map. Spawning reaches are represented by the yellow lines and the non-spawning reaches are represented by the pink lines.

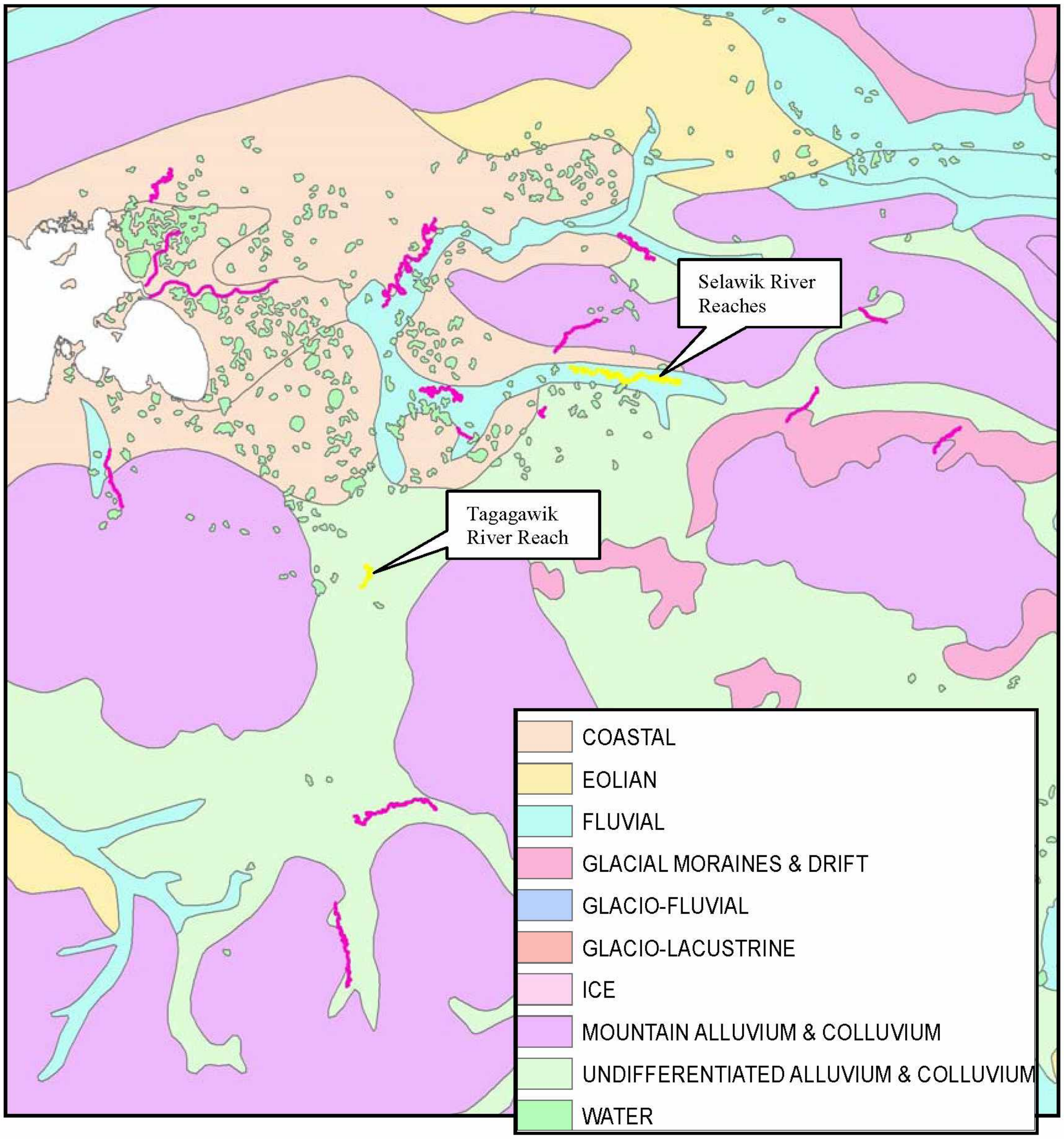

Figure 6. The sample reaches situated over the surficial geology map. Spawning reaches are represented by the yellow lines and the non-spawning reaches are represented by the pink lines.

relief terrain and coarse resolution DEMs prevented the creation of a basin-wide derived stream network (Figure 7).

Statistical Analysis

Discriminate function analysis degenerated during model building as a result of the data set variables. The model incorrectly classified one of the known spawning areas as non-spawning. The model also incorrectly classified roughly one-half of the non-spawning areas as spawning (46.67%) as spawning. The eigen value was 1.

SAR FN1

Image pixilation blurs linear features such as river banks at spatial resolutions coarser than 5-m (Priestnall and Aplin 2006). In the Selawik River spawning area, the river channel is narrow (35 m to 70 m), and there are many gravel bars and a few islands within the banks of the river. The narrow channel width and the large channel features (e.g. gravel bars and islands) combined to limit our ability to reliably obtain clean, water- and/or ice-only pixels. As a result, river ice characterization could not be automated and a quantitative classification of ice was not obtained. However, the visual interpretation of ice conditions within the SAR FN1 imagery appeared to agree with the aerial photos (Figure 8).

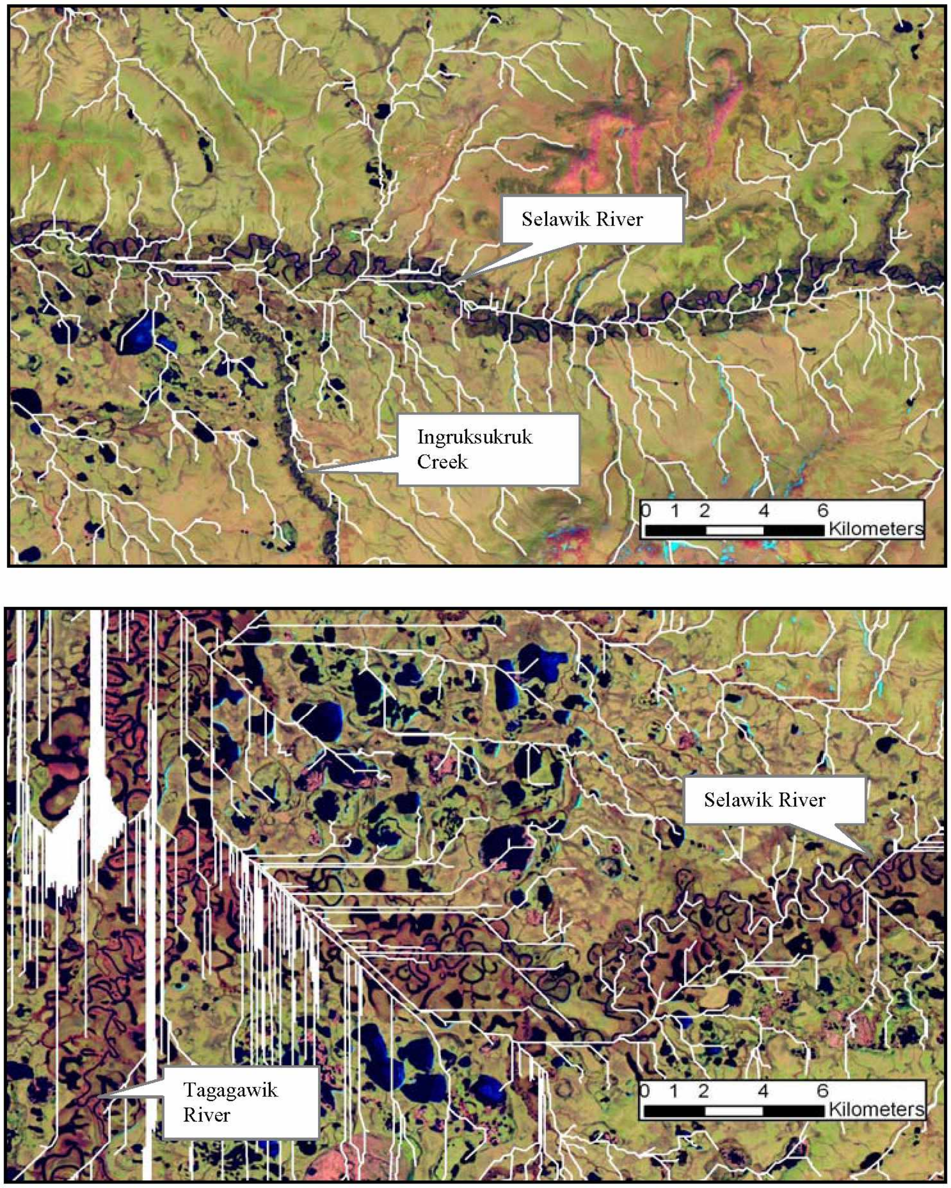

Figure 7. Examples of the DEM-derived stream network failure in areas of low relief. The white lines are a polyline feature converted from the derived stream raster. The top scene is representative of an area transitioning out of low hills, while the bottom scene covers an area of the flood plain. A Landsat image (background) provides a comparison against actual river position.

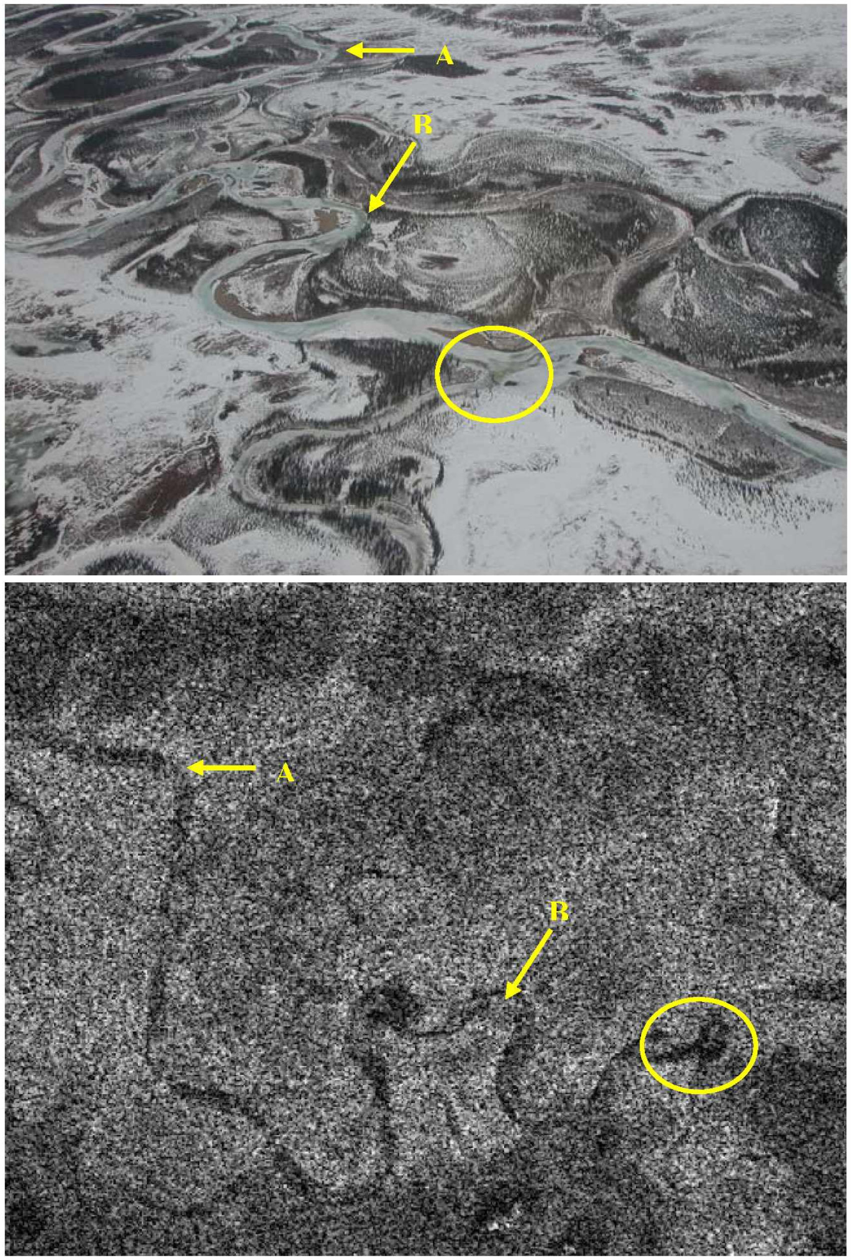

Figure 8. Example of aerial photo and SAR FN1 image comparisons. These are both centered on the Ingruksukruk Creek mouth. The arrows designated A and B are points of reference along the river. The circles refer to the same area of open water or water on ice at the creek mouth. The aerial photo was taken 26 April 2005 and the SAR FN1 image was acquired 1May 2005.

DISCUSSION AND RECOMMENDATIONS

The greatest difficulty encountered in this study was the lack of current, high resolution remotely sensed data and maps. For example, the data gained from the two map layers (surficial geology and permafrost) may not be ideal in that while the GIS layers were created within the last 12 years, their source data is based on out-of-date surveys. The surficial geology map was derived from two separate source materials originating from 1955 and 1960 (NPS and USGS 1999). The permafrost map was derived from O. Ferrians' 1965 source map (USGS 1996). The lack of a more current permafrost survey and coverage is especially an issue in light of the impacts of climate change on permafrost conditions (Hinzman et al. 2005).

The accuracy of stream locations in an artificial stream network derived from a DEM is dependent of the resolution of the DEM from which it is obtained (Walker and Willgoose 1999; McMaster 2002). While not a substitute for actual stream location, an appropriate artificial stream network can be used to extract hydrological attributes. In GIS, these stream networks can determine stream linkages, stream orders, and drainage areas to a highly accurate level (Fisher and Rahel 2004). The difficulty lies in developing an appropriate stream network for areas of low relief if a spatially appropriate DEM is not available. For this study, the derived stream network was adequate to extract information regarding stream linkages, stream orders, and drainage areas only in the areas of higher relief. The stream network was not appropriate for use in low-relief portions of the Selawik basin (Figure 7).

A major consideration when dealing with remotely sensed imagery and maps is the uncertainty that may be introduced by these representations, especially in terms of numerical modeling studies. There is an important role for these data sources; however, the nature and magnitude of potential error from the source data itself and the level of error propagated through the derived secondary data must be fully considered (Priestnall and Aplin 2006). For example, previous studies reveal that channel slope may differ substantially from observed field values (Montgomery et al. 1999; Massong and Montgomery 2000). To address these uncertainties, I recommend that derived values of habitat parameters be verified through ground-truthing to the extent possible. To reduce the amount of potential error introduced into predictive modeling studies, the quality of data used should be appropriate for the scale at which the study is focused. To that end, Alaskan researchers should advocate for new, better acquisitions of remotely sensed imagery. For example, the National Elevation Dataset (NED) is working to establish a 10-m NED DEM, but it is currently only available for the conterminous states (USGS 2008). The NED is an ever-evolving dataset updated bimonthly to incorporate the "best available" DEM data. As federal and state agencies and governments obtain current, higher quality remotely sensed data for their areas of interest, these acquisitions will serve to fill in the huge data gap that is the current state of Alaska high resolution coverage. It will be an enormously expensive endeavor to create such coverage for

Alaska and will likely take more than decade to accomplish. It is recommended that these efforts occur in cooperation and collaboration at local, state, and federal levels.

Some of the statistical challenges encountered by catchment-scale assessments include the inherent multivariate nature of the research problems; lack of true replication; collinearity between explanatory variables; and spatial autocorrelation of landscape data (Johnson and Gage 1997). Furthermore, the independent variables are largely qualitative in nature, not strictly quantitative (Table 3). Permafrost and surficial geology characterization were unavoidably categorical; however, even variables such as percentage slope were best qualified as types rather than as absolute values when measured at coarse landscape scales (Walker and Willgoose 1999; Clarke and Burnett 2003).

While discriminate functions analysis is highly appropriate for this type of study, habitat use by spawning inconnu limits the sample set available for statistical analysis. The output eigen value of 1 seemingly accounts for 100% of the variance explained in the dependent variable. This perfect eigen value was most likely a result of the small data set forcing the variance explanations (J. F. Bromaghin, USFWS, personal communication). The lack of spawning reaches restricted the data set available for statistical analysis (Williams and Titus 1988). No matter how many non-spawning reaches were randomly generated for comparison, modeling efforts were hindered by the inherent habitat selectivity of inconnu. With that in mind, future application should only be considered if the following sampling rule can be met: "[f]or discriminate analysis of ecological systems with homogenous dispersions, choose the total number of samples per group to be at least three times the number of variables to be measured" (Williams and Titus 1988).

While no definitive in-stream habitat studies are available for inconnu spawning habitat, in-stream features such as temperature, substrate type, and groundwater are known to affect spawning selection in other salmonids (Bjornn and Reiser 1991). Fine-scale processes and characteristics, such as hyporheic flow and substrate quality, are driven by the morphologic features of the channel containing them (Geist and Dauble 1998; Kasahara and Wondzell 2003; Coulombre-Pontbriand and Lapointe 2004). Channel features at the reach scale, e.g. pool/riffle morphology, gravel bars, and islands, are determined by the slope of a reach and its water and sediment inputs from the contributing drainage (Frissell et al. 1986). Slope specifically plays a large role in determining the structure and composition of the channel substrate (Beechie and Sibley 1997; Montgomery and Buffington 1998). The slope of a reach, along with its sediment load and water discharge, is in turn determined by climate and underlying geologies (Frissel et al. 1986). Biologic communities are influenced by fine-scale habitat variables, which are in turn determined by drainage basin morphology (Richards et al. 1996). Geomorphic processes occur at various scales, and each one plays some part in determining the structure of the river (Thompson et al. 2001). The multiscalar relationships between physical characteristics and their relevance to aquatic communities allow us to reasonably develop a large-scale heuristic habitat model for inconnu spawning habitat selection. However, at this time, the lack of sufficiently accurate and appropriate data layers prohibits such numerical modeling at this scale.

Despite my inability to generate accurate quantifiable data for statistical modeling of inconnu spawning habitat at this time, I was able to develop qualitative information regarding the known inconnu spawning habitat within the Selawik River drainage. In both the Tagagawik River and the Selawik River, spawning occurred in areas with very high sinuosity and very low slope. Specifically, spawning in both areas occurred in areas of transition from high elevation to low elevations (Figure 9).

Fishes in northern latitudes are greatly influenced by winter conditions, including minimal winter flows and river ice conditions. Winter flow can decrease drastically as water is converted to ice and as precipitation occurs in the form of snow. These two occurrences influence fish habitat parameters critical to young-of-the-year survival, including reduced oxygen levels and limited ice-free habitat (Powers et al. 1999). Because of these adverse abiotic conditions, groundwater influence on winter habitat is an important resource. Groundwater flows act to maintain free-flowing water; moderate water temperature and limit ice development; and influence water quality, i.e. provide movement of nutrients and dissolved oxygen (Baxter and McPhail 1999; Powers et al. 1999).

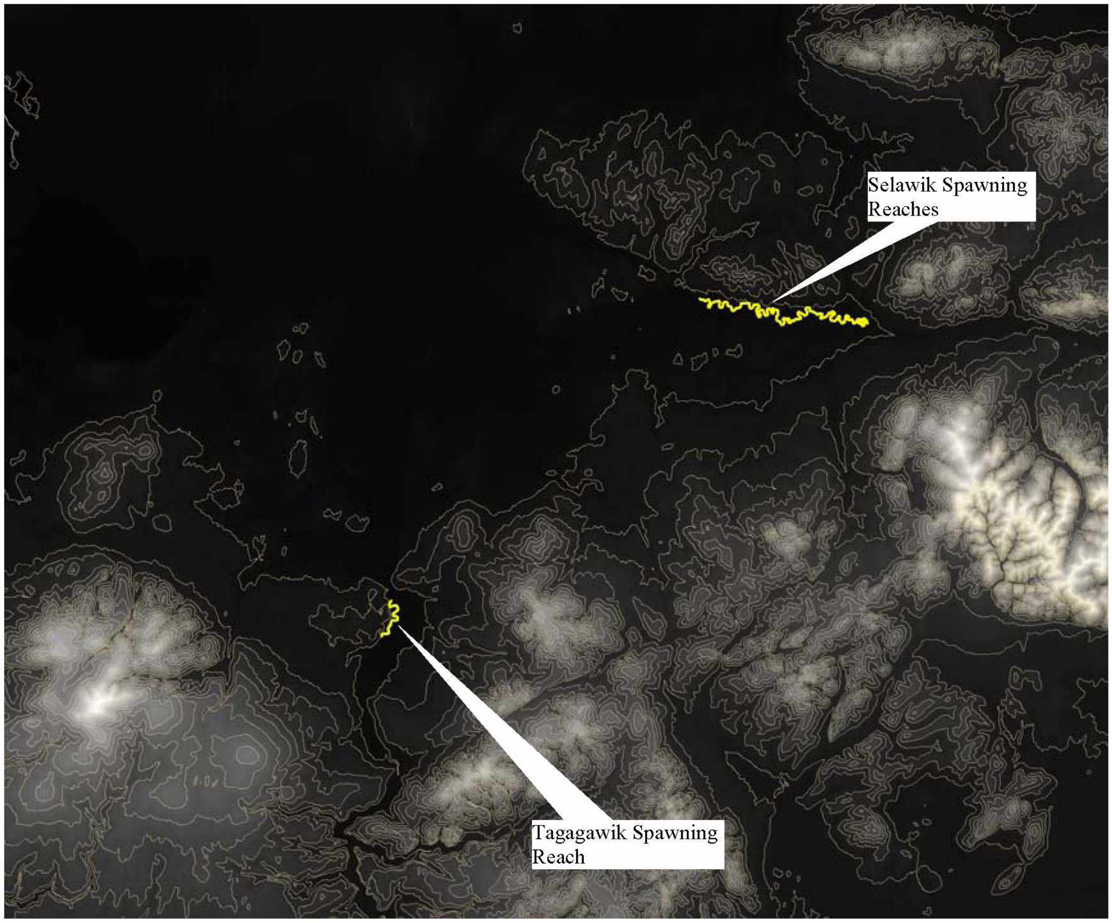

Figure 9. Demonstration of the spawning areas occurring in areas of transition from high to low elevation. The DEM (background) and 50 m contour lines provide topography. The yellow lines indicate the known spawning areas.

Preferential use of localized and widespread areas of upwellings by spawning salmonids has been widely reported (Sowden and Powers 1985; Bjornn and Reiser 1991; Geist and Dauble 1998; Baxter and McPhail 1999), including data on groundwater as it relates to egg survival. As mentioned previously, literature linking groundwater-related habitat selection and coregonids, including inconnu, is not yet available; however, our understanding of its importance to other salmonids implies that groundwater may also be important to inconnu. Areas of water that remain ice free in arctic systems often indicate groundwater (Cunjak 1996; Brown 1999; Beltaos 2000). Anecdotal observations of known coregonid spawning areas that remained ice-free during winter months (R. J. Brown, USFWS, personal communication) strengthen the implication of groundwater importance for whitefish spawning habitat selection.

SAR FN1 is an effective tool for remotely monitoring ice conditions. Image acquisition products are affordable, easily and quickly obtained, and weather independent. Even in smaller river systems such as the Selawik River, visual interpretation of ice classes provides accurate information for locating areas of dark ice/open water (Figure 8; Puestow et al. 2004). In larger river systems, river ice classification can be automated and the classification results quantified (Weber et al. 2003; Gauthier et al. 2006). SAR FN1 gives us the ability to locate potential areas of favorable overwintering and spawning habitat throughout the winter in remote, inaccessible rivers. Additionally, SAR FN1 holds potential as a tool for climate change monitoring in subarctic and arctic river systems.

I used GIS and remotely acquired data and maps to exam the spatial components of inconnu spawning habitat. This effort succeeded in providing habitat attributes and establishing some spatial patterns for spawning areas. However, the available data resolution was not sufficient for numerical modeling efforts. These spatially explicit questions will continue to pose unique and difficult challenges in Alaska until affordable, high resolution coverages become readily available. In conclusion, the approach and tools used in this study will only become more valuable to the field of fisheries as issues of climate change and human development alter the habitat available to our fishery resources in Alaska.

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